



JPL Phase Retrieval Camera

Andrew Lowman, Dave Redding,
Joe Green, Scott Basinger
Yuri Beregovski, Randy Hein
Cathy Ohara, Fang Shi

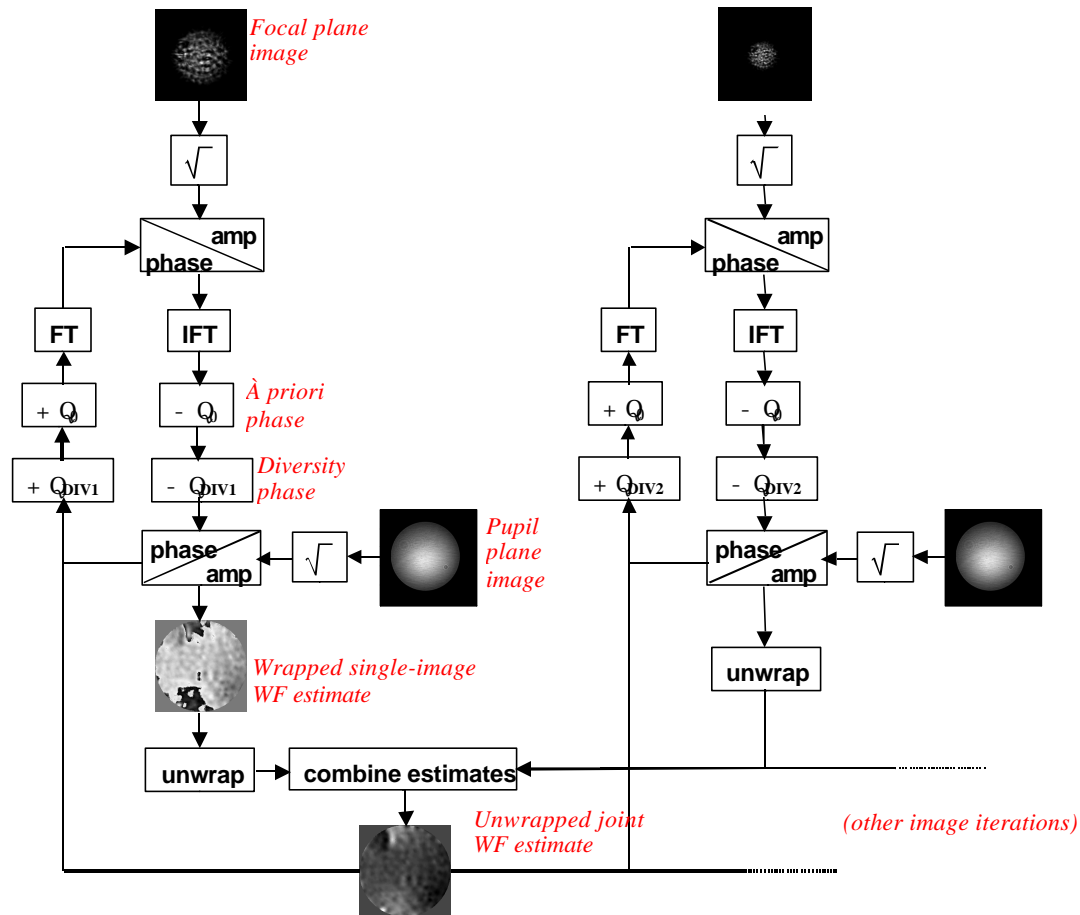
Jet Propulsion Laboratory
California Institute of Technology

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Overview

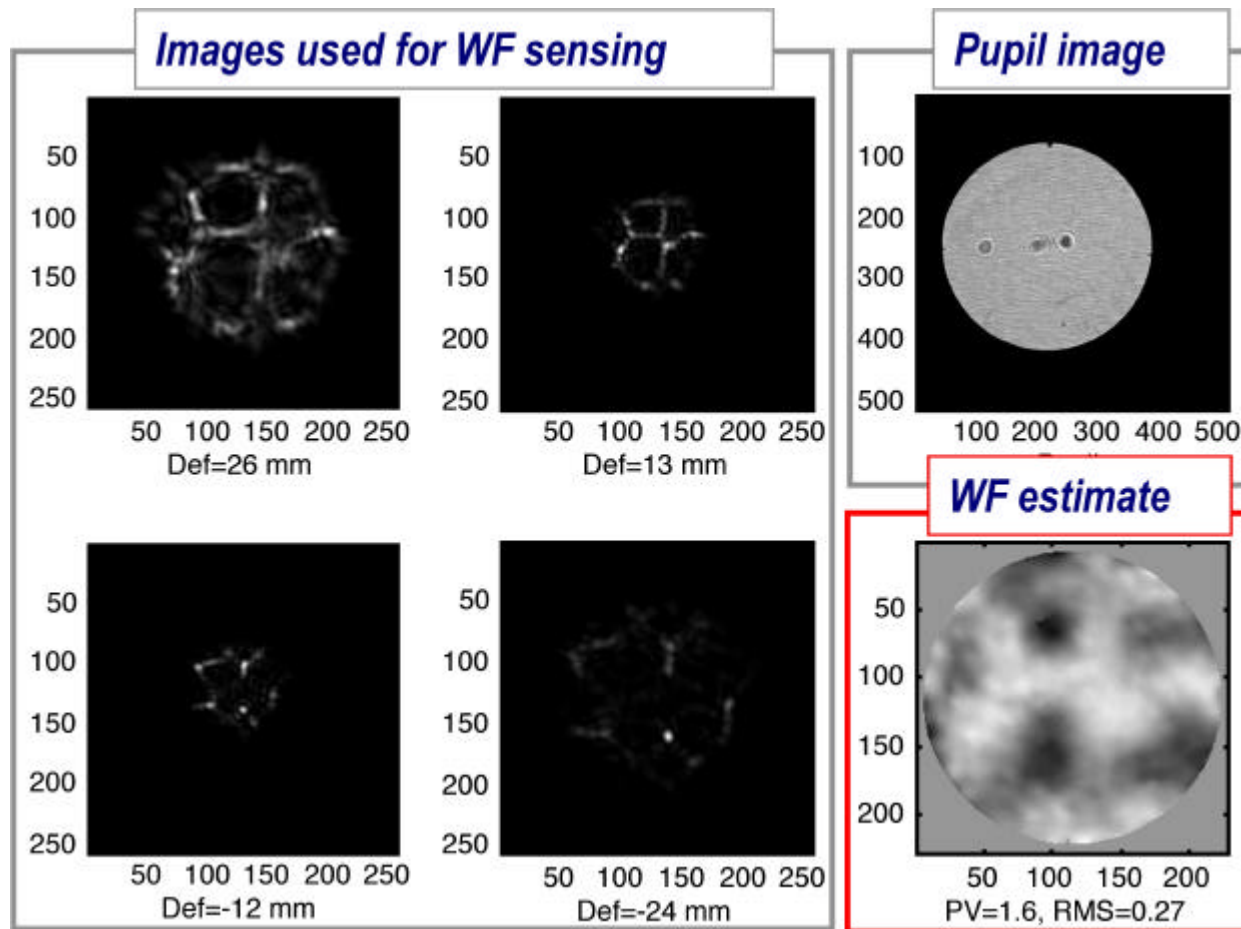
- NGST Phase Retrieval Camera (PRC) is a portable, self-contained device for phase retrieval wavefront sensing
- Useful for optical testing in high-jitter environments
 - MSFC test chamber for NMSD and AMSD mirrors
 - NGST Contractor testbeds
- Enables wavefront control experiments outside NGST's Wavefront Control Testbed (WCT)
 - Phase retrieval experiments
 - DM testing
 - Early experience sensing and controlling NGST primary optics
- Capitalizes on WCT hardware/software infrastructure

Modified Gerchberg-Saxton Phase Retrieval



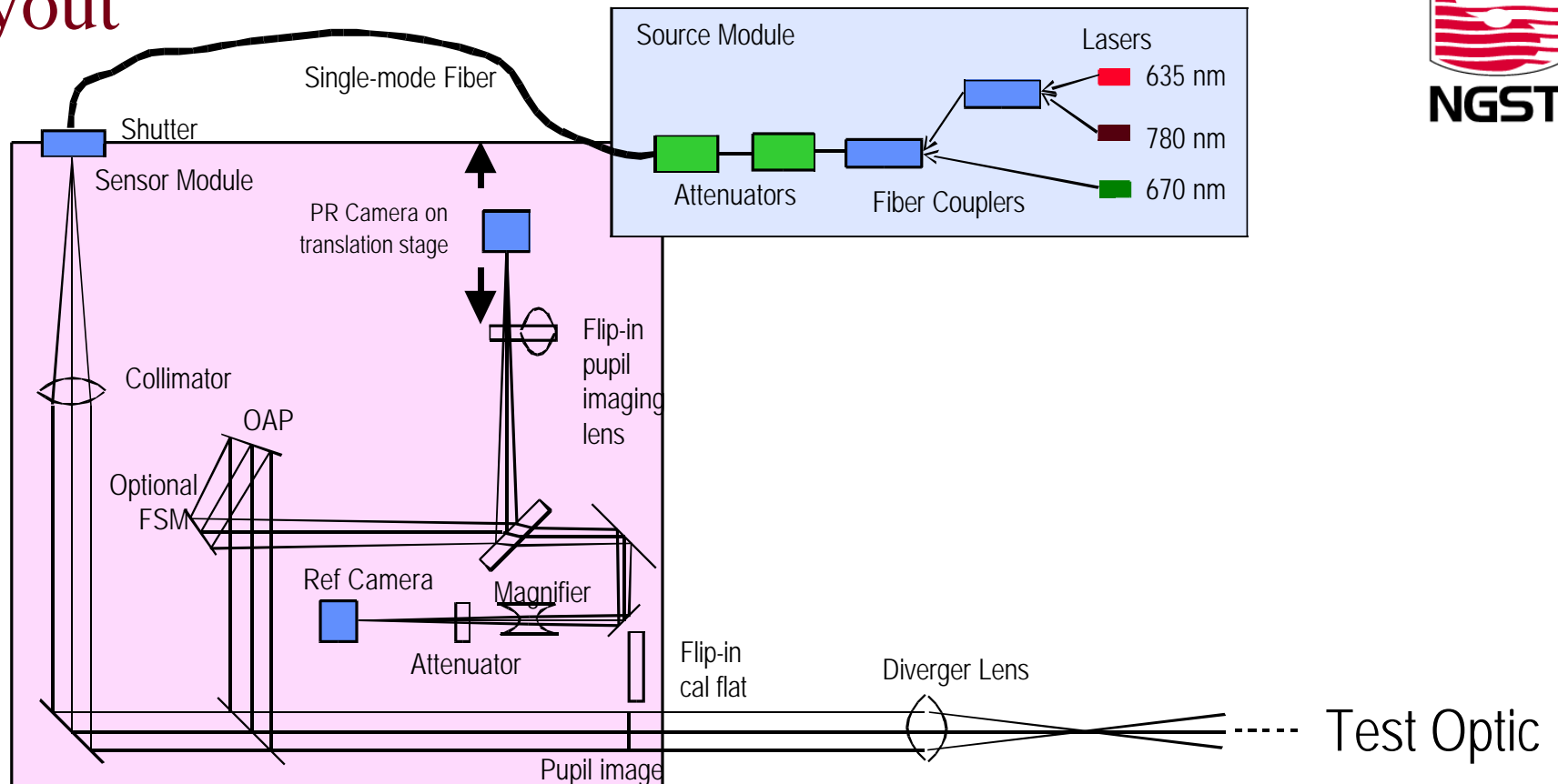
- Gerchberg-Saxton inner loop iterates between pupil and image planes
 - FT from pupil to image, IFT from image to pupil
 - Constrain field at image and at pupil by replacing amplitude with sqrt of image data
- Defocused images improve visibility of aberrations
 - Spread out effects over many pixels
 - Reduce impact of jitter, other blurring
 - Reduce contrast between low, high- f effects
- Subtracting known phase (Q_0 , Q_{DIV}) from the iteration reduces dynamic range
 - Q_0 is systematic across all images
 - Q_{DIV} is difference between images from embedded MACOS model
- Multiple images overdetermine solution to ensure uniqueness
 - Provides more data without introducing new unknowns
- Phase unwrapping allows estimation of $WFE > \lambda$
 - Joint unwrapping improves unwrapping robustness
- *Prescription Retrieval also used*
 - *Complementary algorithm provides more dynamic range, less spatial resolution*
 - *Used to find Q_0*

WF Sensing Example



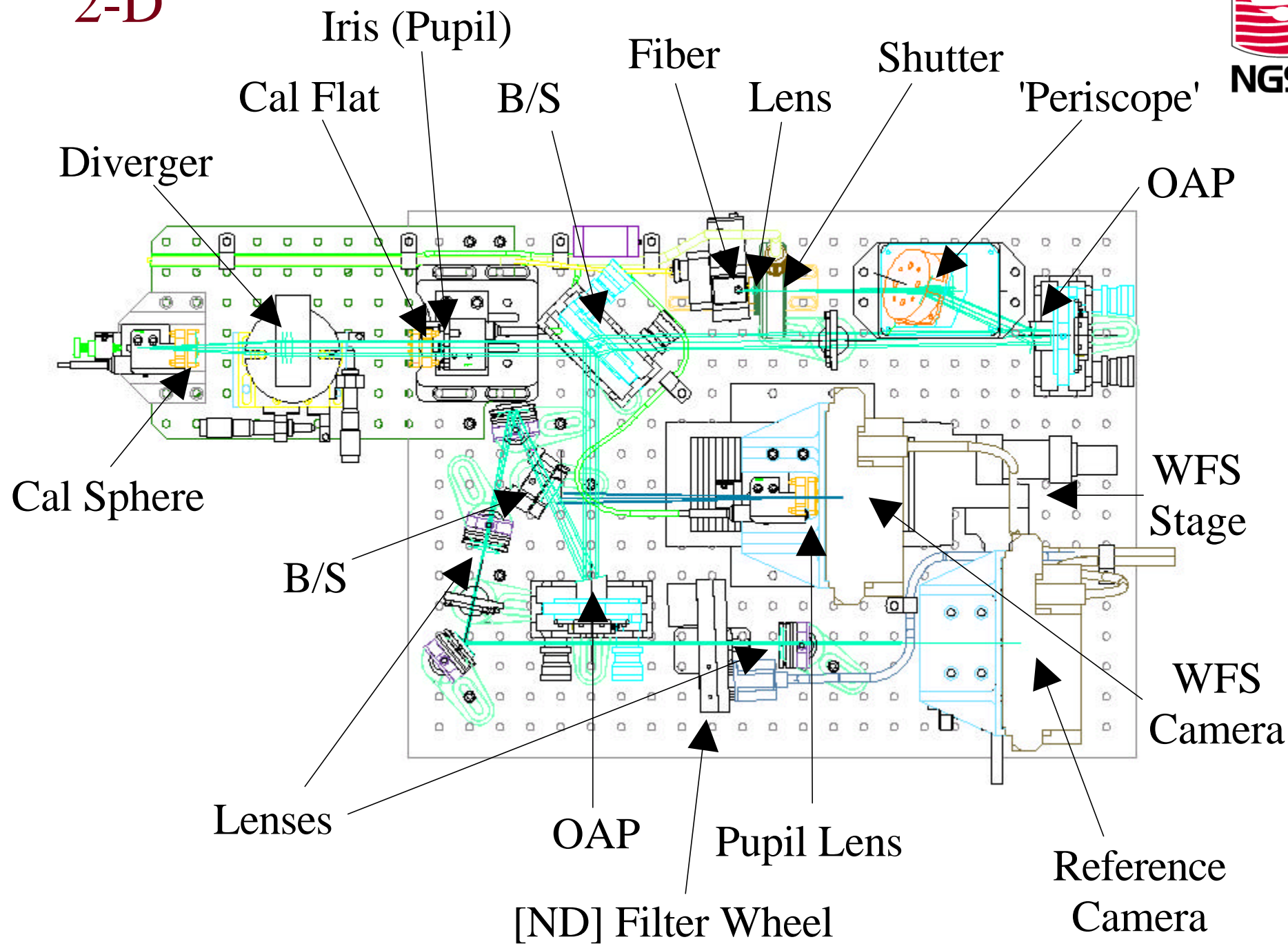
- WCT experience shows WF sensing performance:
 - Repeatability = $\lambda_{633}/110$; PRC is better sampled and should do better
 - Range = a few waves P-V deviation from nominal
 - Relatively tolerant of jitter, lab seeing

Layout



- 2- or 3-color source module for measuring segment piston
- 0.3 millisecond shutter to freeze seeing, jitter
- Test optic imaged onto iris (pupil) for telecentricity
- Camera on translation stage for WFS
- Reference camera to register boresight

2-D



Source Module



- Multiple fiber-coupled diode laser source
- Output from single mode fiber connected to sources by fiber couplers
- Fiber-coupled laser diodes
 - Wavelengths 635, 670, 780 nm readily available
 - Temperature and current stabilized diodes give high amplitude stability (0.1% variation over one hour)
- Inline fiberoptic attenuators control source flux

Phase Retrieval Channel



- Provides imagery for phase retrieval (including prescription retrieval) processing
- System telecentric in image space
- ~ Nyquist sampling ($f/25$)
- Science-grade CCD camera
 - 9 μm pixels, TE cooler ($+ 10\text{ }^{\circ}\text{C}$), 768 by 512 format, Photometrics SenSys
- Translation stage implements focus diversity
 - Newport 4" fast stage
- Flip-in pupil imaging lens
 - New Focus motorized flipper
- Flip-in flat provides for self-calibration
 - New Focus motorized flipper

Reference Channel



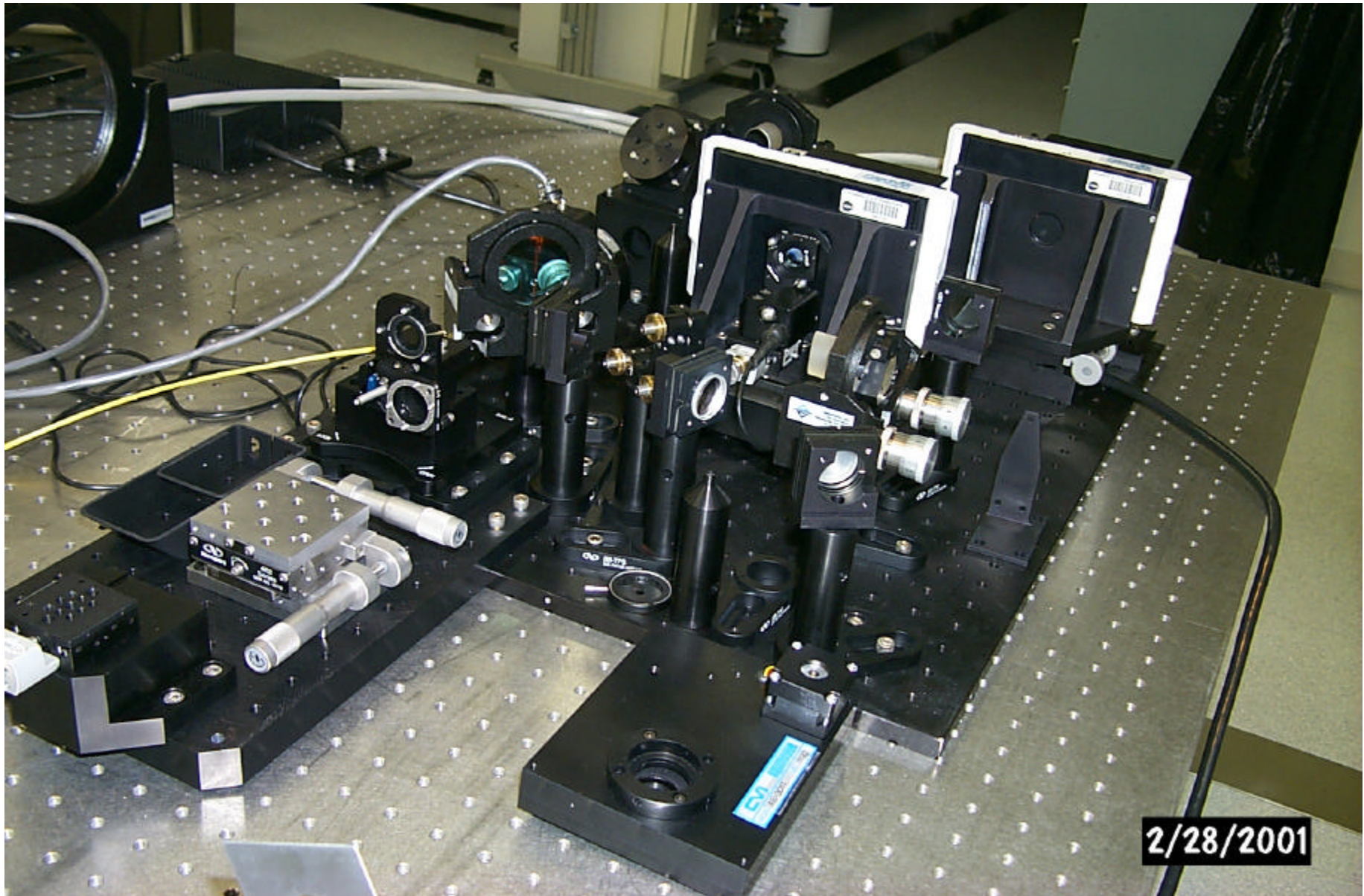
- Provides boresight jitter information
- Takes images simultaneously with PR images
 - Magnified (4X) in-focus PSF provides centroid accuracy
 - Neutral density filters permit full-well operation
 - Source intensity is varied to assure full-well in PR camera
 - Calibration with cameras in focus determines relative boresight
 - Jitter is common-path between cameras
 - Shift-and-add processing of PR camera images establishes correct centering for PR processing

Computers and Software



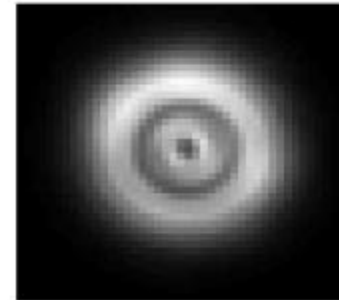
- PC travels with box to drive stages, grab images, provide communications to Executive
 - Utilizes modified WCT PC software
- Operated locally or remotely using SPARC workstation
 - Utilizes modified WCT Executive software
 - Phase and prescription retrieval
 - Internet-based communications
 - Matlab GUI driven
 - Parallel processing for speed (~3 minutes for phase retrieval)

Assembled Hardware

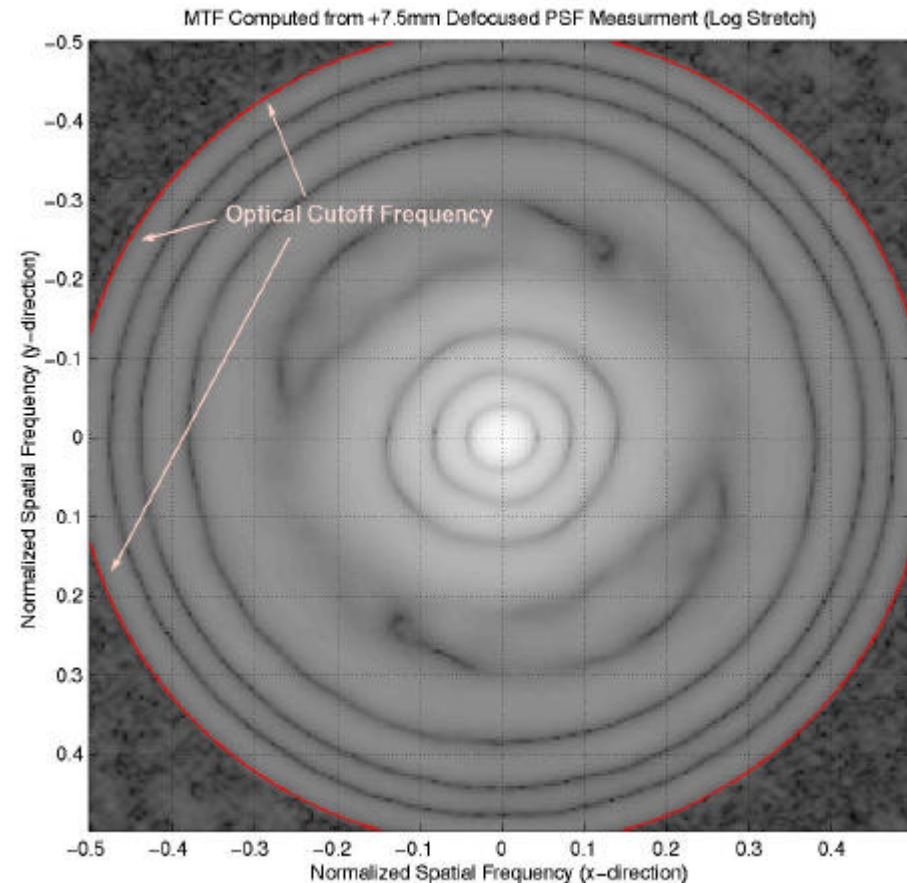


Calibration of F/# and Best Focus

- The location of the optical cutoff frequency indicates that the system is about 4% undersampled with the fixed aperture.
- This also indicates that the F/# of the PRC is 25.6 ± 0.1 . ($\lambda = 675.5\text{nm}$ and $\Delta = 9\mu\text{m}$)
- By optimizing the defocus Zernikes to match the defocused PSFs we can calibrate both F/# and best focus.



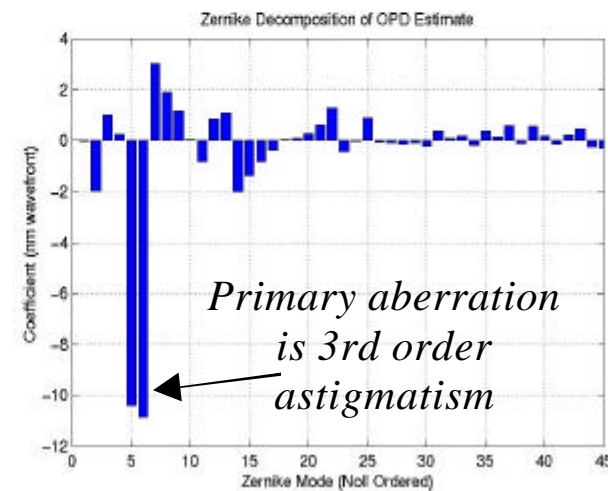
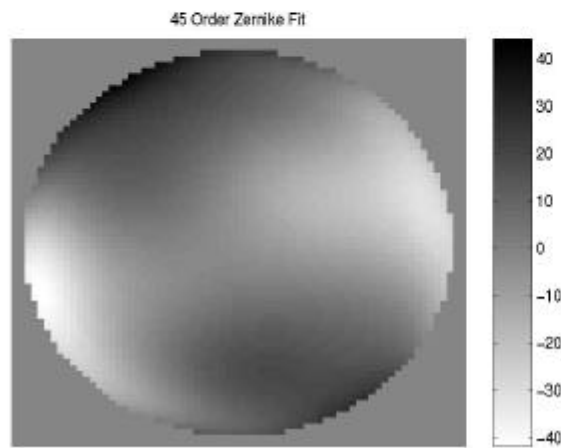
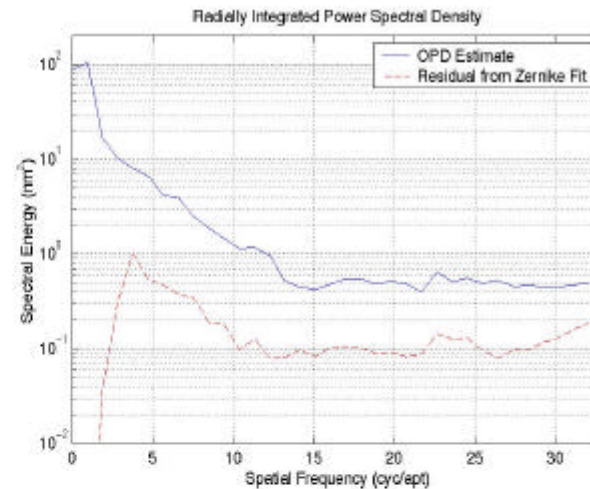
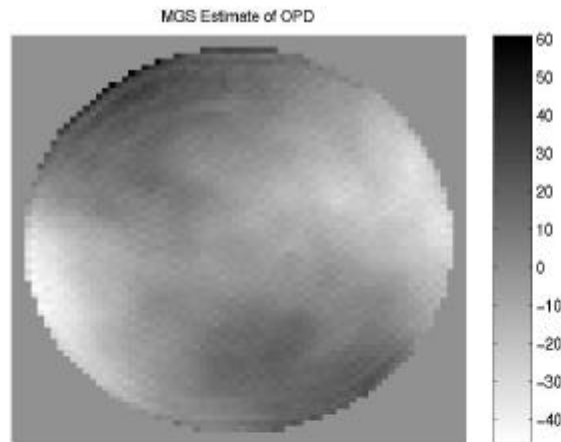
PSF measurement
taken at +7.5mm, 10
frames co-added



Parameter	Calibration
System F/#	25.5
Best Focus:	-2.84 mm
Inducible Defocus:	0.285 waves/mm

Phase Retrieval

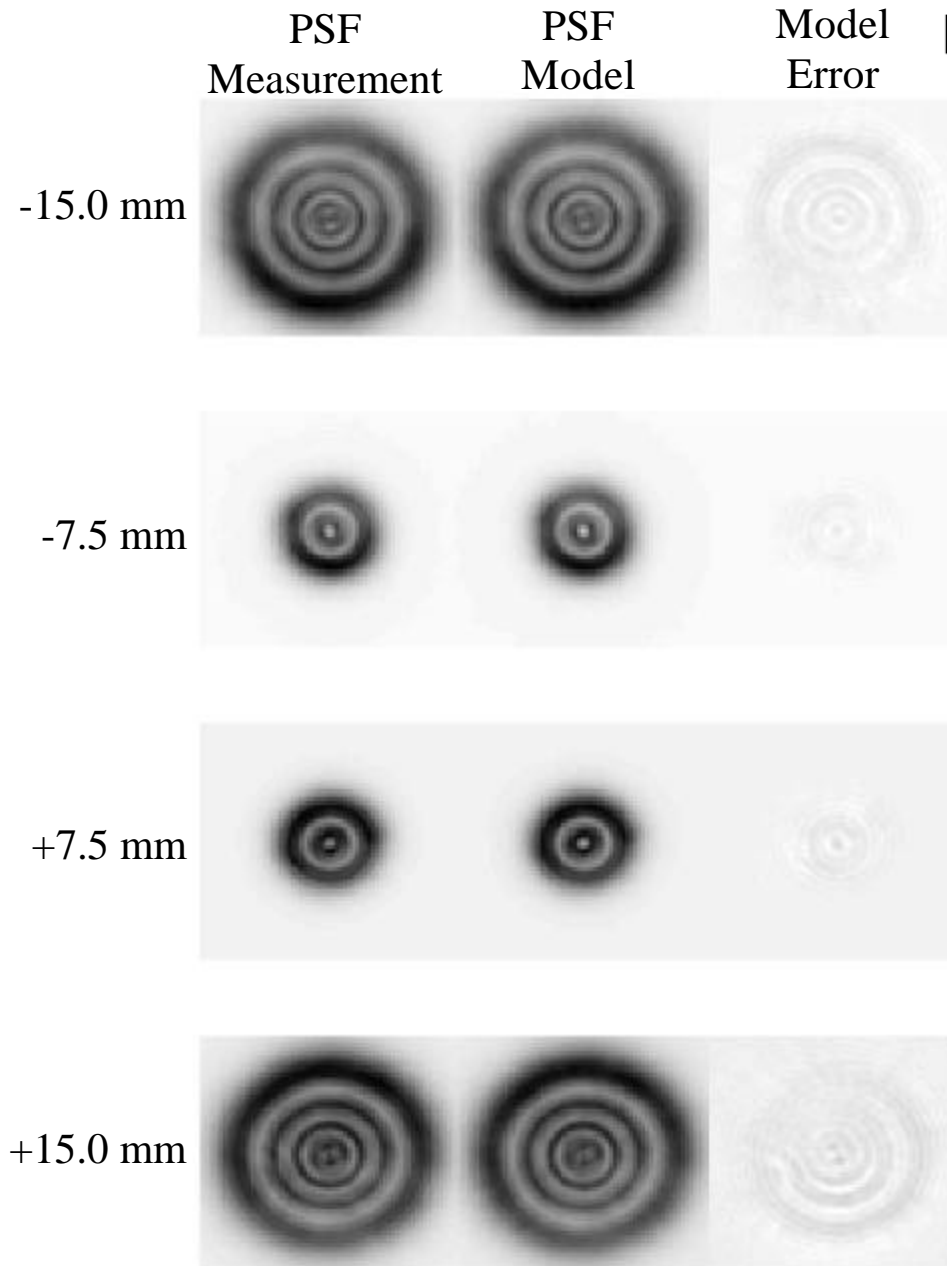
- Used $\pm 15\text{mm}$ and $\pm 7.5\text{mm}$ imagery with the MGS algorithm
- Resulting OPD indicates 16.5nm ($0.025 \lambda_{670}$) rms wavefront error, primarily due to 3rd order astigmatism.



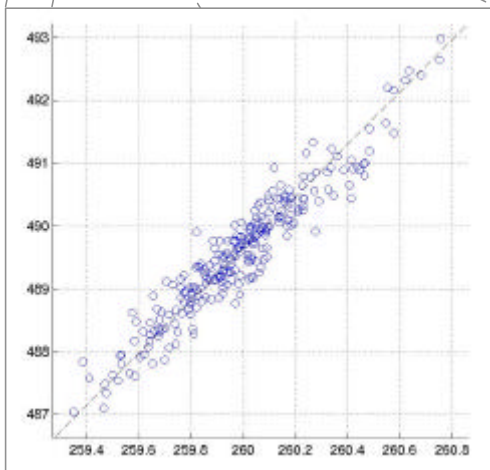
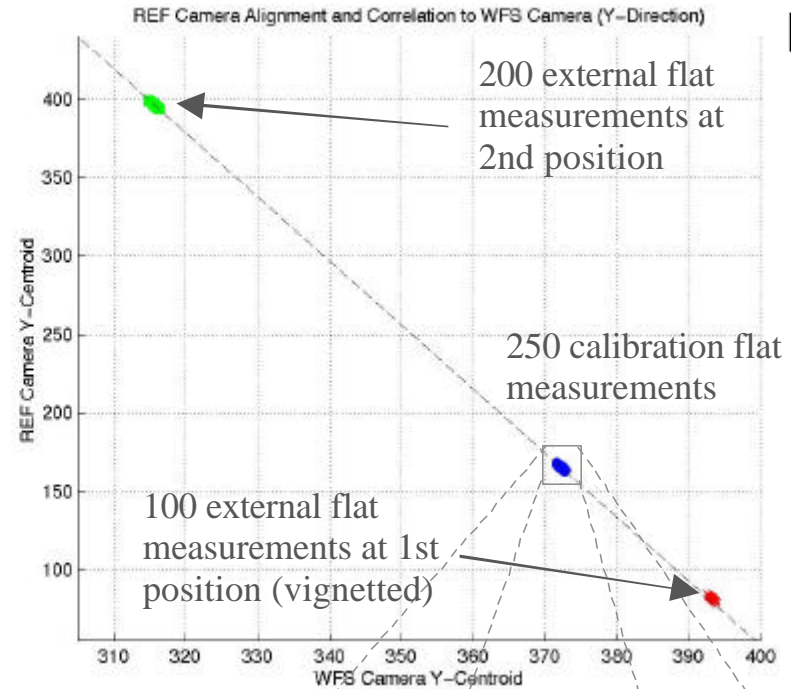
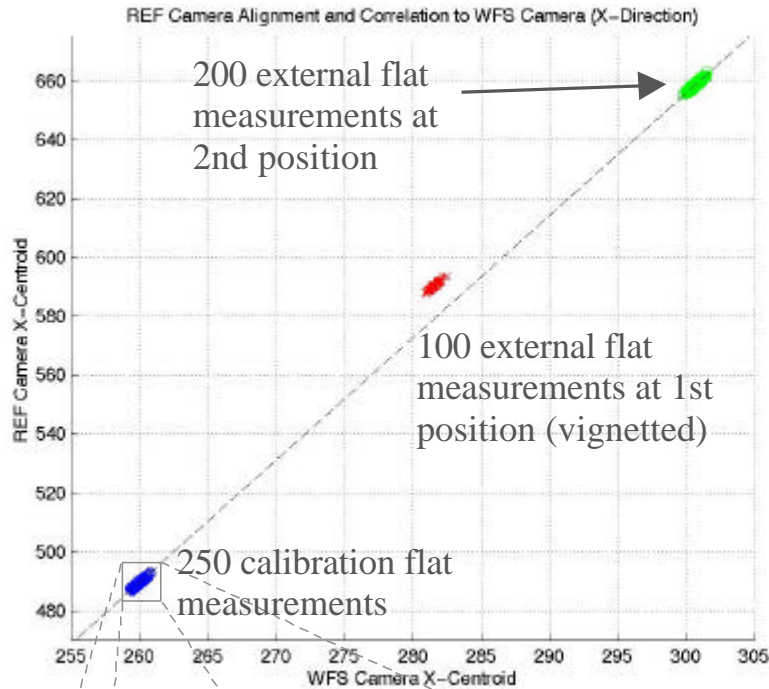
Phase Retrieval (continued)



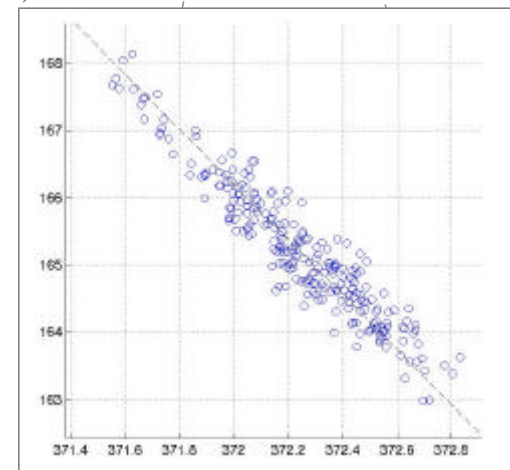
- OPD estimate from MGS provides a good fit over the set of defocused imagery.
- 0.2 pixel low-frequency jitter measured and modeled
- Fit improves by including a high-frequency (kHz) blurring kernel with $\sigma=0.6$ pixels
- Negative images are displayed to highlight modeling errors



Reference Camera Magnification Calibration



- Reference camera provides excellent signal for co-adding WFS camera images.
 - >95% correlated for calibration flat data.
 - >99% correlated for external flat data.



Current Work



- Calibration
 - Reference camera boresight shift with ND filter
 - Effect of shutters on internal jitter
 - WFS repeatability
- Optics
 - Fiber alignment (center illumination pattern)
 - OAP (reduce astigmatism) ???
 - Stake with epoxy
 - Install diverger lens
- Testing
 - Dynamic range
 - Low-quality spherical mirror + distorting mount
 - Compare to interferometer
 - High jitter cases

Conclusion



- Phase Retrieval Camera assembled, undergoing testing
- Good performance
 - Small internal wavefront error
 - $0.025 \lambda_{670}$ RMS
 - Small internal jitter
 - 0.2 pixels on wavefront sensing camera
 - Highly correlated with reference camera